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Re-engineering of GRRASP to support distributed and collaborative analysis of critical infrastructures

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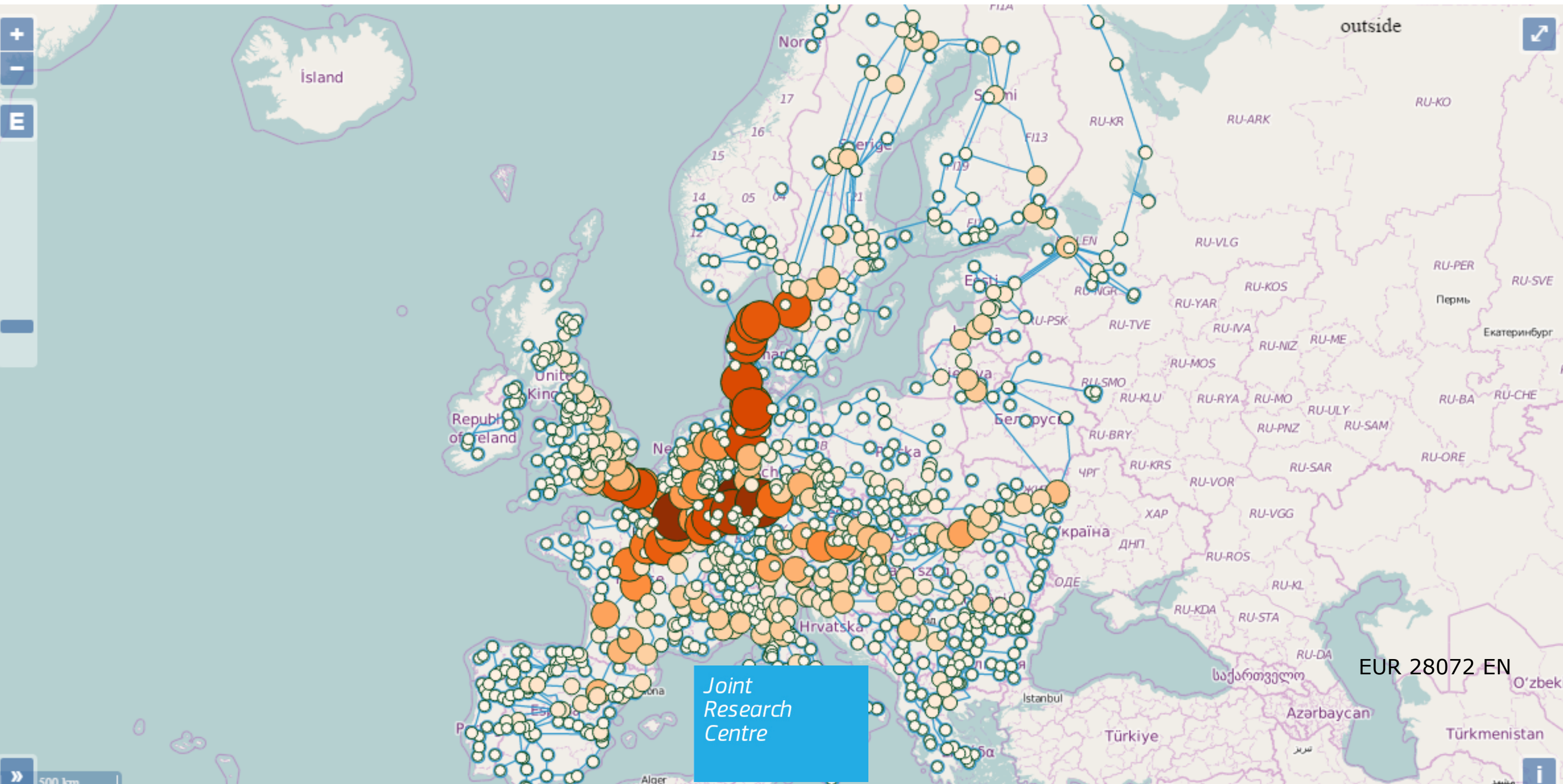

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Contents

Abstract

Critical Infrastructure Protection (CIP) is getting increased attention as a result of the number of man-made threats (terrorism, malicious attacks, cyber events) and natural disasters. In addition to that, critical infrastructure systems are becoming more and more interconnected with the introduction of ICT technologies and thus isolated events may lead to large-scale or even continent wide disruptions. Interdependencies between critical systems are a key factor that needs to be considered in the framework of their analysis and simulation with the objective to improve their resilience.

This is not simply an EU approach but also in the US, the National Infrastructure Simulation and Analysis Centre (NISAC) has developed a number of tools for the analysis of critical infrastructure systems, supply chains, etc. which obviously are tailored to the US reality. In Europe, most tools are developed responding to national efforts and focus on the specific issues that need to be addressed at national scale. Obviously this approach shows its limitations in case large-scale infrastructures that expand across borders and jurisdictions need to be assessed.

Data sharing concerns are a major issue in the field of critical infrastructures analysis and this is a factor that somehow hinders the development of shared tools and methodologies for the analysis and simulation. Collaboration among CI stakeholders is indeed an open issue in the framework of CI analysis and simulation. In order to foster collaborative analysis, it is important to make sure that all stakeholders agree on a common terminology and to provide tools that enable collaboration while ensuring data security and privacy through the whole analysis cycle.

Critical infrastructure owners and operators have agreed on several occasions the importance of developing tools and methodologies for modelling and simulation. It is true that in the recent years, several tools have been developed and these can be used for the assessment of a wide number of disruptive scenarios. It seems though that most of such tools lack the features to be used at a European scale and therefore fail to become standards. In principle, they represent ad-hoc efforts tailored to the needs of a particular region/state/sector. Consequently, often they lack the capability to scale up to international level.

In response to the above-mentioned issues, JRC developed the Geospatial Risk and Resilience Assessment Platform (GRRASP). GRRASP is a World Wide Web oriented architecture bringing together geospatial technologies and computational tools for the analysis and simulation of critical infrastructures. It allows information sharing and constitutes a basis for future developments in the direction of collaborative analysis and federated simulation. It takes on board security concerns in the information sharing process, thanks to its ability to manage users and roles consistently. Based entirely on open source technologies, the system can also be deployed in separate servers and used by EU Member States as a means to facilitate the analysis of risk and resilience in critical infrastructures.

The current version of the GRRASP architecture represents an important improvement

over the previous versions. The technical infrastructure of the project has benefited from the integration with the Drupal Content Management Systems (CMS), which streamlines the development and update process of the platform and allows the integration with a number of third-part modules, fostering interoperability and bringing collaboration capabilities to a new level. Thanks to these features, the platform seems to properly meet the objective to provide an analysis framework that can be used by member states competent authorities and operators in order to improve risk and resilience assessment at local, regional, national and international scale. In addition, it can represent a tool to support the development and testing process of new models, as well as CIP-related training activities.

CHAPTER 1

Operating principles and specifications

GRRASP is a geospatial-enabled platform for the analysis of critical infrastructures. It can be considered as kind of GIS-based operating system that enables the combination of GIS technologies with mathematical models (applications) in order to provide a complete analysis environment with strong visualization and simulation focuses. In this chapter we overview the background information related to its current release.

1.1 Background information on policy recommendations

The guidance and selection of certain approaches and technologies for the development of GRRASP has been provided by the EPCIP Directive, its revision process and the staff working document on “Risk assessment and mapping guidelines for disaster management”. These documents provide to a certain extent the framework for developing these activities, while our involvement and interaction with MS and authorities in the framework of the revision of EPCIP contributed in understanding the constraints in data availability, ability to share data on critical infrastructures and render those data available to the scientific community.

One element that is clearly stated in the above mentioned documentation is the need for assessing interdependencies among sectors, the impact of critical infrastructure disruption taking an all-hazards approach and the need to collect data on risks from the EU MS. In addition, methodological approaches for risk assessment (not only for critical infrastructures) are also mentioned.

Risk assessment has been a central element in the EPCIP review discussions. Risk assessment for critical infrastructures is a domain where many different approaches and tools exist therefore the landscape is fragmented. This can be attributed to the fact that risk assessment was developed to respond to specific risks following mostly a sectoral approach and that no generic risk assessment methodology for critical infrastructures can be developed. On the other hand assessing resilience has only recently gained attention and it is expected to gain more and more attention in the next years. This can be attributed to the complexity and variety of threats that critical infrastructure operators need to phase and as a consequence putting risk barriers following a pure risk management approach is out of the scope mainly for cost reasons. A point that needs clarification is that with the term resilience we may refer to many different domains (CI resilience, societal resilience, etc.) but for the purposes of the present work we refer to resilience of critical infrastructures, which is mostly technological.

According to [1], a modern approach for risk and resilience assessment for critical infrastructures should consider these two disciplines in a correlated manner. This is not straightforward since these two concepts require different mindsets and approaches. Risk assessment aims to identify those risks for which barriers have to be built whereas resilience provides the means, measures and maybe tools to absorb the shock of disruption and bounce back in an efficient manner. Of course many different definitions exist for resilience but we would like to avoid at this point to enter in this discussion as it exceeds the scope of this report.

It is true though that for assessing risks and resilience for critical infrastructures, it is necessary to consider interdependencies. An example of classification of interdependencies among critical infrastructures can be found in [2]. Assessing interdependencies is dictated by the following elements:

- Infrastructures are becoming more and more interconnected
- Disturbance phenomena will continue to affect bigger parts of critical infrastructures
- Variety and sophistication of threats is ever increasing
- Events that take place in systems and infrastructures that are not part of an operator's risk management may have a huge impact on an operator's capacity to operate
- Defence through isolation is not an option due to the interconnectedness of modern infrastructures

In the various EPCIP Annual Work Programmes and more specifically in EPCIP 2011 AWP, JRC has been entrusted with the task to develop tools and methodologies for resilience, interdependencies, and risk assessment. Responding to this need we aimed to provide an innovative approach and a tool that can be used by CI stakeholders, policy makers, researchers, etc. All the above mentioned documents and observations have shaped the form and defined the specifications of Geospatial Risk and Resilience Assessment Platform (GRRASP).

Although GRRASP from its very beginning was based on a web based architecture (thus allowing for remote access and collaborative work), these features were not fully developed. In addition it was not possible to link together different instances of GRRASP in order to share data among the different groups of users. This requirement drove the reengineering of GRRASP architecture to its current form.

1.2 Architectural specifications

In this section we overview the technical considerations leading to the formulation of the software architecture of the current version of GRRASP, as it will be detailed further on in the next chapters.

Open source software The current version of the software is entirely built based on open source software which has certain advantages.

- the possibility to minimize maintenance costs
- the opportunity to fully control the development of the different components of the project and their integration within the objective of the tool.

- no fees are required by the end user to maintain the platform

More details on EC strategy on open source software can be found at http://ec.europa.eu/dgs/informatics/oss_tech/index_en.htm.

Integration with a Content Management System Content Management Systems (CMSs) are key tools exploited today towards the development of computer applications, especially involving the interaction among programmers towards the creation, improvement, maintenance and structuring of new software. The introduction of a CMS component in the GRRASP architecture serves as a basis to guarantee a more standardised interaction among project components. A CMS is also useful, in this context, in order to properly manage the user-server interaction and the server-to-server information exchange, which was entirely missing in the previous version and it is what renders possible the link between GRRASP instances installed in different servers. This is increasingly becoming a key factor in the GRRASP development, in order to let the users access, produce and share content, a large amount which may come from external servers GRRASP could be configured to connect to.

Modular architecture The modularity of the GRRASP architecture is considered a key factor to allow the integration with new data sources, mathematical models and geospatial tools being developed in time. This is also a key factor to enable users to provide themselves additional components to enhance the domain of application of the platform.

Convergence of geospatial data and critical infrastructure modelling Together with its modularity, the GRRASP architecture also has a specific focus on the mathematical analysis of geographically distributed critical infrastructures. Therefore, an effort has been done to provide specific tools to integrate classical representation of geospatial data with analysis components.

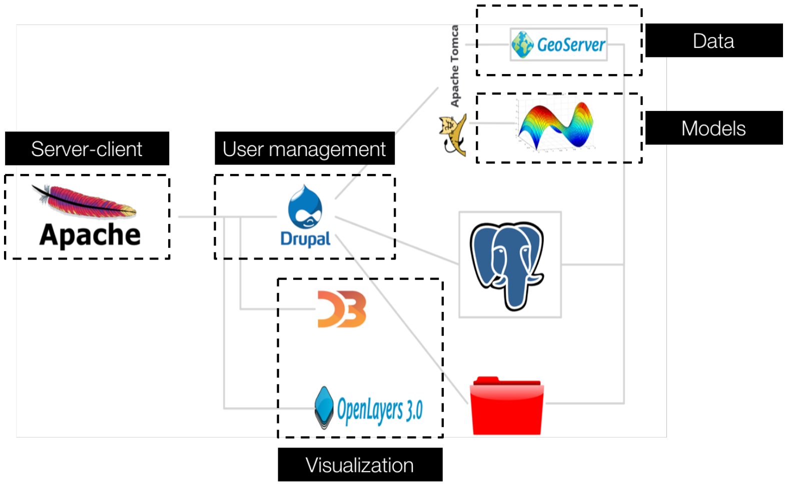

***Figure 1.1:** GRRASP architecture*

CHAPTER 2

Provision of geospatial services

The development of specifications and standards for the provision of geospatial services can be considered as central in the development of many applications related to security of critical infrastructures.The increasing interest in such kind of platforms is motivated by the emerging opportunities to access and combine commercial proprietary data, official government data and publicly available data from various sources, which can be useful to foster geospatially-enabled situational awareness for policy-makers and first-responders.

The GRRASP platform includes tools for the processing and transmission of geospatial data compliant with standards by the Open Geospatial Consortium. In particular, through the embedded GeoServer utility, a variety of such services can be supported.

2.1 Open Geospatial Consortium (OCG) standards

The Open Geospatial Consortium (OGC) is a leading international organization providing open standards for the management of geospatial data. Supported by a wide community of organizations worldwide, its action targets a variety of domains and uses of geographical data according to an interoperability principle. Four industry leaders, Autodesk, BAE SYSTEMS, Intergraph Mapping and Geospatial Solutions and Northrop Grumman Information Technology (IT) have committed significant resources to the Open GIS Consortium's (OGC) Critical Infrastructure Protection Initiative (CIPI). CIPI aims to test the application of interoperable technology to meet critical infrastructure protection needs for coordination of geospatial data and services between national, state, provincial and local governments and commercial and non-government organizations.

OGC standards are technical documents that detail interfaces or encodings. Software developers use these documents to build open interfaces and encodings into their products and services. OGC Web Services (OWS) are OGC standards were created for use in World Wide Web applications. Next in this section we briefly overview some of the most relevant ones for the current implementation of GRRASP. For further details, please refer to http://www.opengeospatial.org/standards.

2.1.1 Web Feature Service (WFS)

The WFS interface standard establishes an interface for the request of geographical features across the web. The features transmitted according to this method represent the code embedding the data that can be used to generate the corresponding map, as well as to process further the data. Furthermore, there is the possibility to provide Transactional Web Feature Service (WFS-T), which allows the creation, deletion, and updating of features, thus expanding the representational capabilities of the service.

2.1.2 Web Map Service (WMS)

The WMS specification defines a protocol for requesting geographical data represented by geo-referenced map images from a server. Thus, in contrast to the WFS case, here the data transmitted are represented by tiled maps. WMS clients can request images from multiple WMS servers and combine them into a single, overlaid view. This standard is supported by a number of existing servers on the web. Here we also have the option to exploit WMS with time support (WMS-T).

2.1.3 Web Coverage Service (WCS)

The WCS standard addresses the transmission of coverages, i.e. collections of data over spatio-temporal meshes. The WCS services supports querying based on spatial criteria and further constraints. Similarly to the case of WFS, the transactional option is supported also in this case (WCS-T).

2.1.4 Further standards

Apart from WFS and WMS, there are a number of further standards available from the OGC. These include, for instance,

- Web Map Tile Service (WMTS): a standard to provide pre-rendered georeferenced map tiles, typically to the advantage of reduced server response times.

- Web Processing Service (WPS): a standard that provides methods for standardizing the requests and responses related to geospatial processing services. As such, the WPS enables the triggering of the processing of geographical data as part of a Web service;

- GeoRSS: a standard allowing the embedding of geographic information in web feeds.

2.2 GeoServer

The provision of geospatial services on the GRRASP platform is currently centred on the interaction with GeoServer (`http://GeoServer.org/`). The GeoServer project is a full transactional Java (J2EE) implementation of a number of OpenGIS Consortium's standards, including those discussed in the previous section. It also provides an integrated Web Map Server. Its role in the GRRASP architecture is to allow access and interaction with geographical data stored in spatially enabled databases, files and outer data sources to be transmitted to the client and visualised on maps in web browsers. Figure 2.1 shows the welcome page of the GeoServer interface.

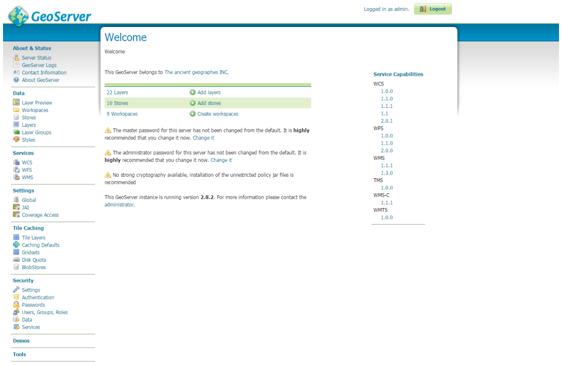

Figure 2.1: *GeoServer main page*

2.2.1 Data structuring in GeoServer

The data sources are organized in GeoServer according to a three-layered architecture, including:

- Workspaces
- Datastores
- Layers

Workspaces are group of data associated to a particular project, while datastores are logical groups of data within a certain project (e.g. gas network data, electrical data, administrative data, etc.). The layers (e.g. airports, railroads, etc.) are the actual data each of which belongs to a workspace and datastore. Workspaces can be added or deleted, datastores can be deleted and both of them can be refreshed when any changes are performed. See Figure 2.2 for an example of a layers list.

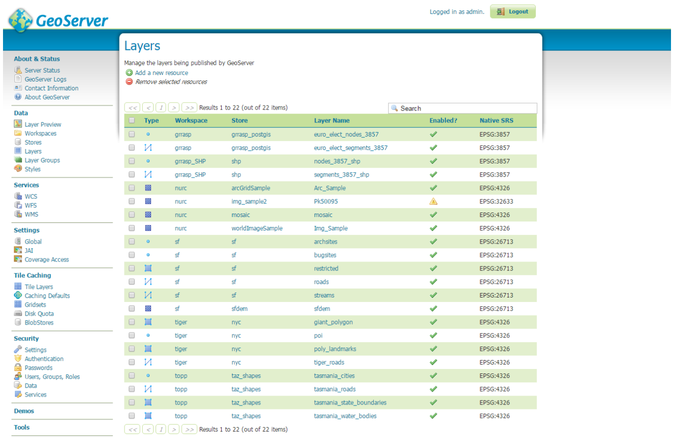

Figure 2.2: *GeoServer layers page*

2.2.2 Connecting GeoServer and GRRASP

In a typical configuration, GRRASP runs on top of a Drupal installation in an Apache server. The interaction between this server and GeoServer can be made transparent allowing transferring data from one server to the other by setting up the Apache Proxy Pass for GeoServer Public Data Access, hence overcoming the “same-origin” policy. We will not go more in detail on these topics, one may find more information on the web.

2.2.3 GeoServer-manager

In order to allow the GRRASP CMS to interact with one or multiple GeoServer instances being part of a GRRASP installation, an ad-hoc Java library was developed and integrated in the platform. This library is based on GeoServer-manager (https://github.com/geosolutions-it/GeoServer-manager), an open-source REST client library allowing a rich interaction with the functionalities of GeoServer. The library is currently under active development in the community, also in order to support the new functions being provided in new releases of the GeoServer platform.

Our library currently supports the querying of GeoServer in order to obtain information about the available content, taking into account data access restrictions per user and per role.

2.3 Storage of geographical data

Different options are available for the storage of geographical data. In this section we provide basic information about some of the most common ones.

2.3.1 Shapefiles

Shapefiles are a geospatial vector data format largely used in the community for GIS implementations. The format supports the representation of various spatial shapes (points, lines, polygons) together with data attributes. What is commonly referred to as a shapefile is actually a collection of files sharing the filename prefix and residing in a common directory. These include three mandatory files with extensions .shp (Shapefile shape format, i.e. the shapefile strictly intended, containing the geometry data), .shx (Shapefile shape index format), and .dbf (Shapefile attribute format). Apart from these three, a number of other files can be included as well to complete the description.

2.3.2 Spatially enabled databases: PostgreSQL and PostGIS

The existence of a relational database is a key feature of GRRASP where data and infrastructure information are stored. However, a simple DBMS is not enough since the spatial extension is necessary to enable the use of this information for GIS analysis. In GRRASP we are using the PostgresQL DBMS which is an open source RDBMS with more than 15 years of active development and a proven architecture that has reached a strong reputation for reliability, data integrity, and correctness. It runs on all major operating systems, this being an important requirement for the development of GRRASP.

PostGIS adds support for geographic objects to the PostgreSQL object-relational database. Actually, PostGIS “spatially enables” the PostgreSQL server, allowing it to be used as a backend spatial database for geographic information systems (GIS), much like ESRI’s SDE or Oracle’s Spatial extension. In addition, the PgRouting extension has been installed to extend the PostGIS

/ PostgreSQL geospatial database the capability to provide geospatial routing functionalities. Hereby we list some organizations that are currently using PostGIS:

- US Davis Soil Resource Laboratory publishes soil inventory data for the southwest United States
- North Dakota State Water Commission manages all their hydrological and spatial data
- Infoterra, a leading European satellite and aerial imagery provider, runs their data provision and sales systems on PostGIS, and stores the complete Ordnance Survey database on PostGIS.
- The national mapping agency of France manages over 100 million topographic features in PostGIS/PostgreSQL and provides read/write access to researchers around the country in more than 100 scientific fields. This approach is also pertinent to GRRASP.

Figure 2.3 contains a screenshot of the PostGreSQL main page and PostGIS shapefile import/export tool.

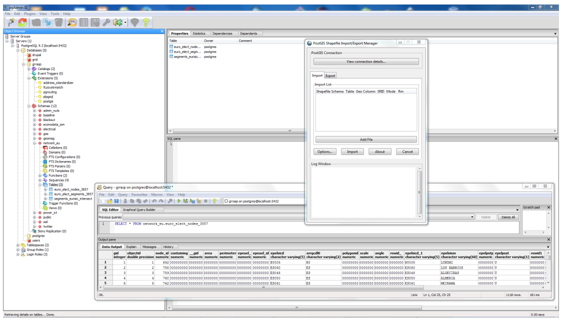

Figure 2.3: *PostGreSQL main page and PostGIS shapefile import/export tool*

2.4 Data preprocessing

In several cases it is necessary to perform data preprocessing, more details on this will be presented in another chapter of this report. However, here we need to briefly provide a few elements on the desktop side of GRRASP that is based on QuantumGIS (QGIS). The later is a cross-platform free and open source desktop GIS application that provides data viewing, editing, and analysis capabilities. This is necessary mainly for preparing spatially based information (topologies of infrastructures) into topologies that can be used for network analysis. The main features of QGIS can be summarised as follows:

- can be used as a stand-alone application
- can be extended with “plug-ins”
- can read and write from/to PostgreSQL/PostGIS database
- can read and write from/to GeoServer making use of OGC standards (WMS, WFS, WPS) and “de facto” (GeoRSS , KML, tiles) geospatial web services

- it uses the Python programming language which is a widely used language for high-performance/scientific computing

This software has already been successfully used in risk and disaster management (e.g. InaSAFE Disaster Scenario Assessment for Emergencies). In Figure 2.4 the interface of the software is depicted.

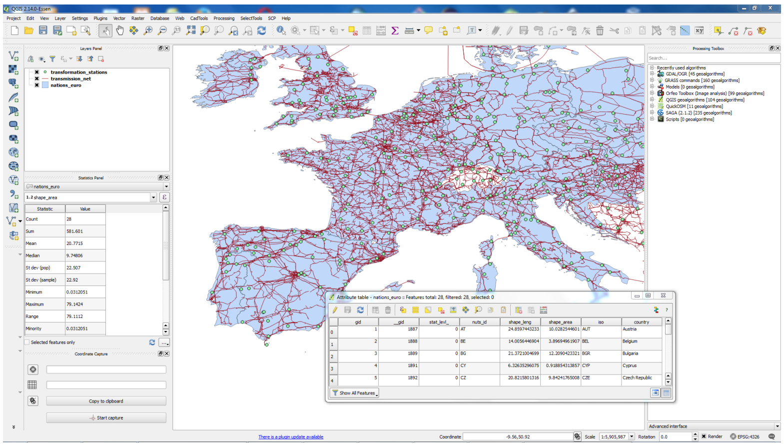

Figure 2.4: *QGIS main page with different geoprocessing tools*

CHAPTER 3

GRRASP interface and layout

3.1 Introduction

In this chapter the details of the GRRASP layout and the general functionalities of the system are provided. An important element for the success of any IT system and in particular for a system that is addressed to non IT experts, is the user interface which needs to be as intuitive as possible. This has been taken on-board and GRRASP is developed in a way that its interface minimises the effort that is required from the end user.

3.2 Programming languages

Client side programming The interaction with the user is performed using two JavaScript libraries, namely JQuery and JQuery UI, whilst the spatial data retrieval from GeoServer relies on the OpenLayers library. The use of OpenLayers makes it possible to integrate a dynamic map in any web page. It can be used to display map tiles and markers loaded from any source. OpenLayers has been developed to extend the use of geographic information of all types.

Server side programming Any procedure performed on the server uses the PHP programming language. In particular PHP seems to be particularly suited for interacting with Matlab which is particularly important for building scientific modules. PHP has been tested both for passing parameters to compiled Matlab modules and using a text based file (e.g. .m file). In both cases it has provided reasonably fast and easy access to the features offered by Matlab.

The PHP Hypertext Preprocessor allows web developers to create dynamic content that interacts with databases. PHP applications are normally found on Linux servers and in conjunction with a database (PostgreSQL in our case). It enables these servers to perform functions similar to the ones provided by the Java Server Pages (JSP). JSP is similar to PHP, but it uses the Java programming language. It is marginally used in the current version of GRRASP.

Based on the PHP programming language, the Drupal 7 CMS platform provides a set of tools for the development of rich web environments. It exploits a modular structure allowing the combination of different elements, both developed by the open source community as well as customised ones. Details about the modules characterising the operation of GRRASP are presented in the next paragraphs.

3.3 GRRASP user interface

The Drupal CMS allows combining the contents with a large set of theming (theming refers to the layout of the page) possibilities. Consequently, it is possible to construct interfaces taking into account website construction principles such as responsive design, panel-based design, etc. The different choices are available at limited reconfiguration cost, allowing the system to be adaptable to different contexts.

This aspects seem important in order to allow the integration of GRRASP in different displaying and operating contexts, allowing for different degrees of detail and articulation in the displayed information. Starting from a standard desktop-oriented interface, it is thus plausible to move towards mobile-oriented interfaces on one side, and on the other to large-panel visualisations (e.g. crisis management rooms).

The currently implemented interface is based on the Bootstrap front-end framework (http://getbootstrap.com/), implemented through the corresponding Drupal theme (https://www.drupal.org/project/bootstrap). This represents today one of the most successful tools for web development and is based on mobile first, responsive principles. The platform has evolved over time, introducing the support for Sass and Flexbox, and is actively supported by the development community of Drupal.

Based on the Bootstrap framework, the GRRASP interface has evolved and now exploits more extensively a multi-page format, providing a rational structuring of the available information and models.

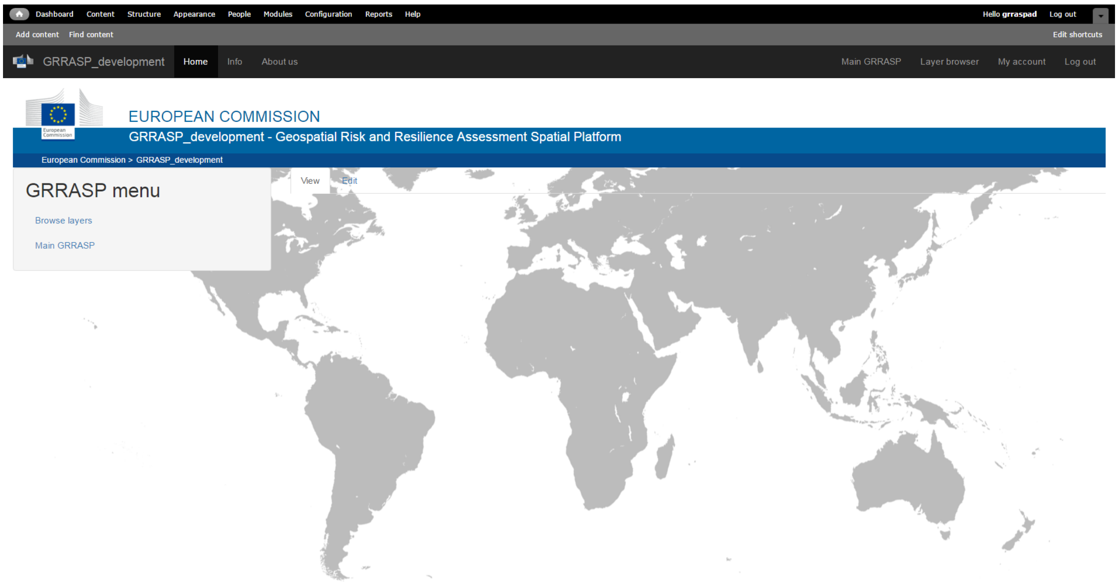

Figure 3.1: *GRRASP welcome page*

3.4 Map displaying module

The client-side map displaying functionalities have been developed based on the open source OpenLayers Javascript library.

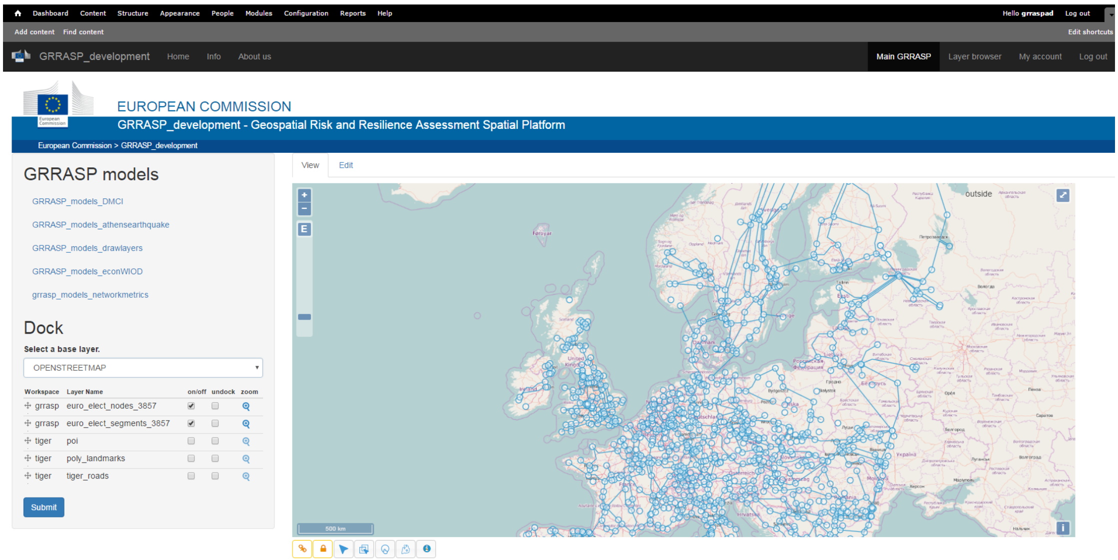

Figure 3.2: *GRRASP main map page*

3.4.1 OpenLayers 3 interface

OpenLayers[1] is a Javascript map visualisation library providing an extensive set of support functionalities for the manipulation of layers and selections. Since the last release of GRRASP, the version of OpenLayers supported by the platform has evolved to version 3. As detailed at http://openlayers.org/en/v3.13.1/doc/tutorials/introduction.html, OpenLayers 3 is currently under active development and presents substantial improvements over the previous version. This includes improved data manipulation possibilities, the developing methods to support the displaying of 3D maps and tools to manage the visualisation of large data sets.

The maps typically visualised in the GRRASP geographic interface consist of a superposition of background and overlay maps. The background maps are obtained as services from external providers, while the overlay maps are either made available by the CMS or obtained from services provider by the map servers specific to GRRASP, e.g. GeoServer. It has to be observed that this architecture also allows the connection to external providers also in the case of overlay maps, which represents a very useful functionality in order to access and gather data for instance from open data providers (e.g. https://data.gov.uk/).

[1] http://openlayers.org

3.4.2 Map styling

An important component of the new version of GRRASP is represented by a richer and more structured approach to data visualisation over the map interface. To this end, we explored the possibility to introduce some of today's trending methods for enhanced geographical data visualisation[3, 4, 5].

In particular, the new release of GRRASP includes colouring methods for the representation of vector data within OpenLayers 3 based on map-specific palettes and colour patterns proposed in ColorBrewer.org and optimised for various objectives (colourblind safe, print friendly, photocopy safe and LCD friendly palettes). These have been embedded into a GRRASP-specific definition of OpenLayers 3 styling options. The objective is to provide families of mutually compatible and extensible parameters for the display of different classes of geographic features, especially in relation with the needs of the scientific visualisation objectives. The style definition introduced in the architecture can support the quantitative association with numerical data such as simulation outputs, through the introduction of scaling and interpolation methods. By necessity, the different styling options proposed can be extended easily and are meant to effectively support different visualisation needs (e.g. neighbouring regions, graphs).

Figure 3.3: *Style example of polyline layer*

3.4.3 GRRASP map interaction toolbars

3.4.4 Layers toolbar

This toolbar provides access to the layers currently selected among the ones provided by the available services. The toolbar has a drag-and-drop functionality and allows the removal, the activation/deactivation of a layer's visualisation on the map and the zoom functionality to include the whole layer in the screen. It is also possible change the background layer with different styles (satellite, hybrid,..) using the select menu.

3.4.5 Selection/popup toolbar

This toolbar provides the activation and deactivation of the following functionalities:

- Activate the selection of only one layer (the selection can be applied on one layer or on all the visible ones).
- Lock and unlock the selection
- Selection (by point or by box)

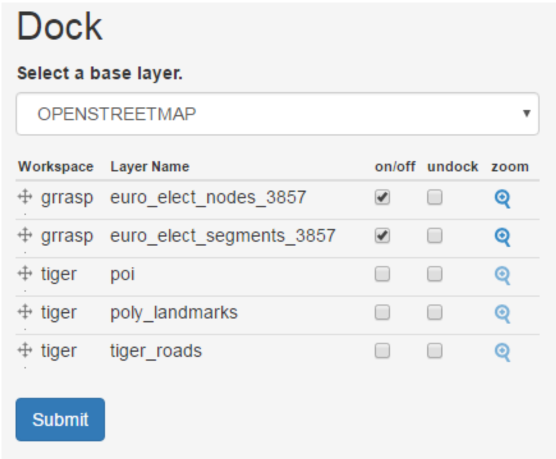

Figure 3.4: *Layers toolbar*

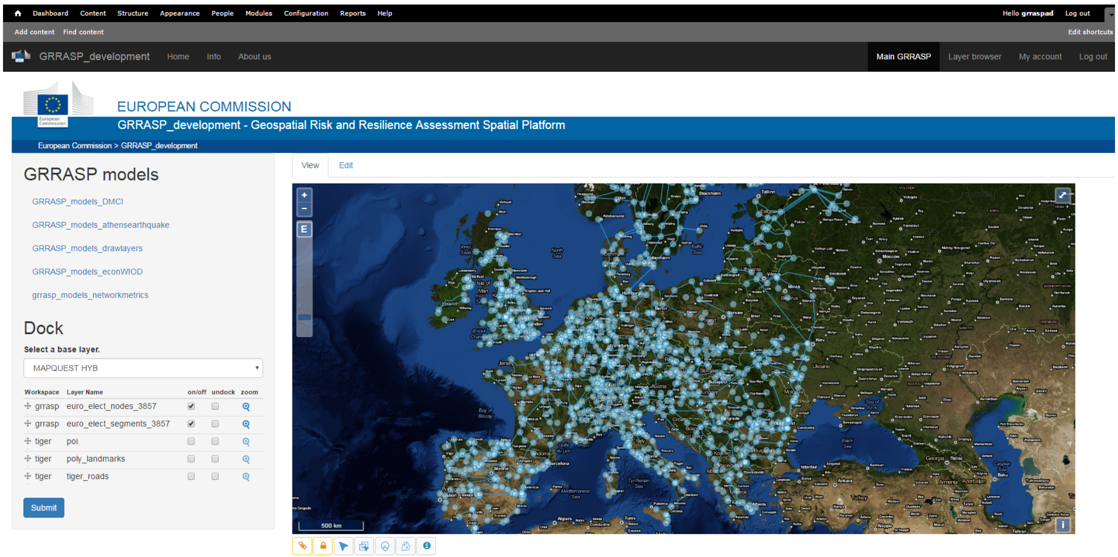

Figure 3.5: *GRRASP main page with base layer set as hybrid*

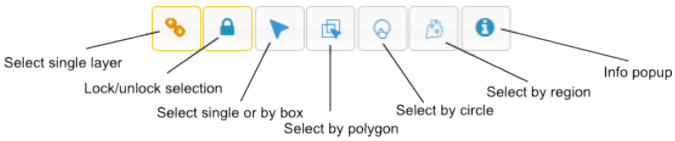

Figure 3.6: *GRRASP selection/popup toolbar*

- Selection by polygon
- Selection by circle
- Selection by region
- Data query through popup

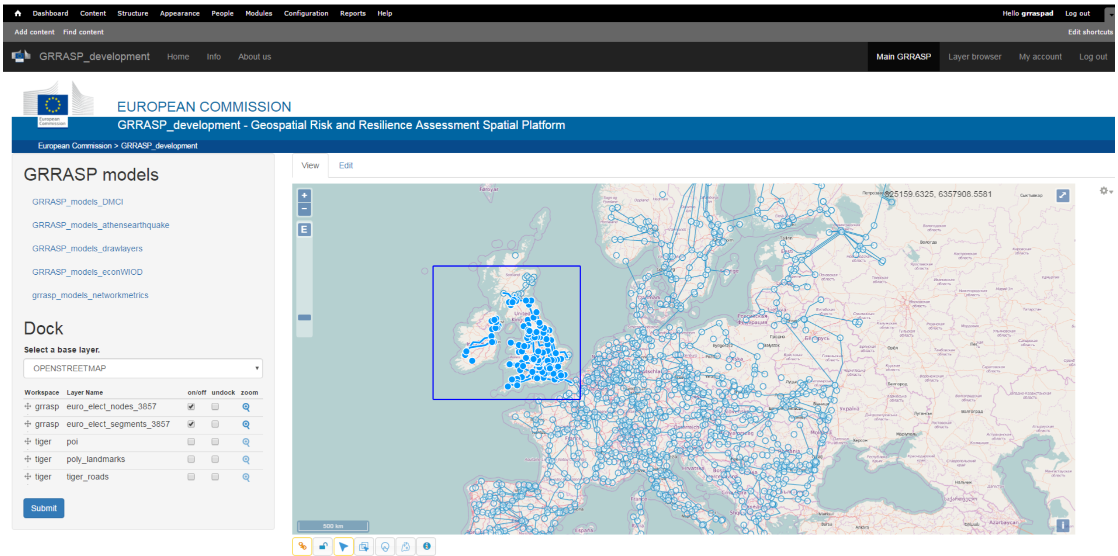

Figure 3.7: *Selection by box*

3.5 Layer browser

This section provides access to the list of all layers provided by GeoServer with useful parameters and a preview. It is possible to select layers and send them to the layer toolbar for visualisation.

3.6 Visualisation of non-geographic scientific data: D3.js

In order to support the visualisation of scientific data such as simulation outputs on the client side (in fact on the end user's web browser), GRRASP is equipped with the D3.js library. D3.js is a JavaScript library providing extensive support for data visualisation and for generating a variety of charts and diagrams. It uses pre-built JavaScript functions for the selection of objects, the creation of SVG objects, the application of styles and the addition of dynamic effects. It supports various data formats, including json, geojson and CSV.

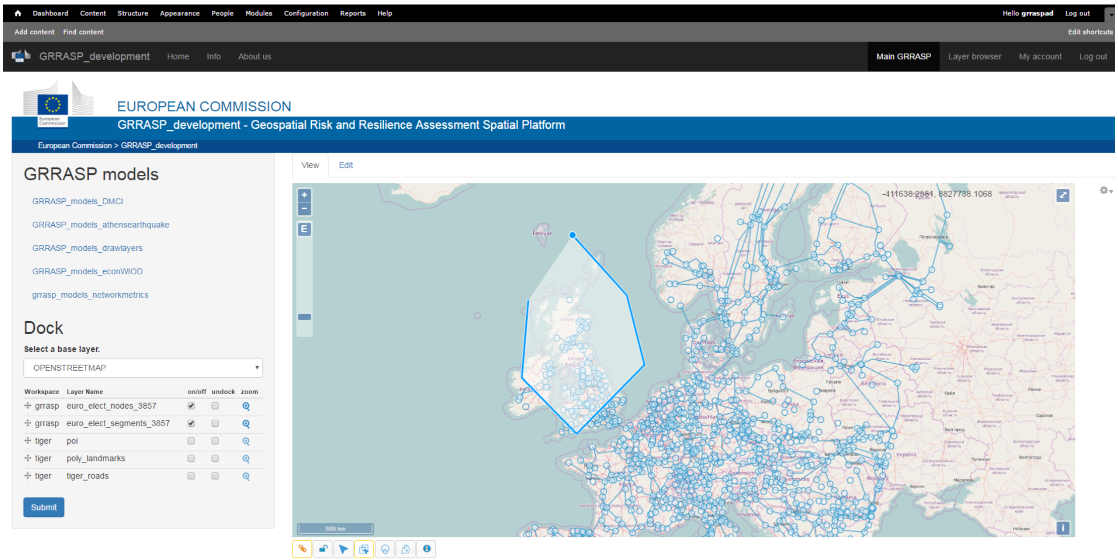

Figure 3.8: *Selection by polygon*

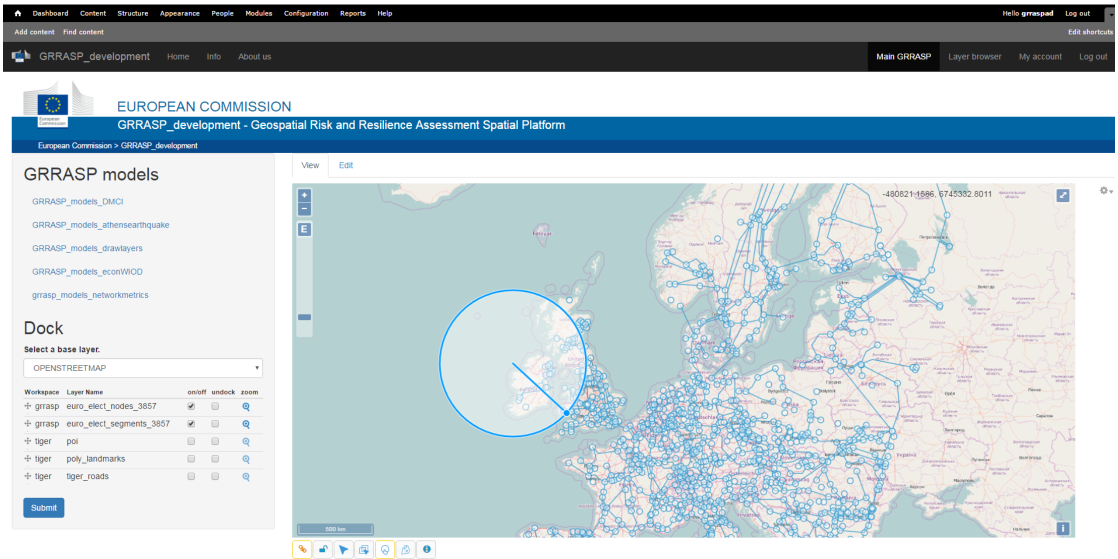

Figure 3.9: *Selection by circle*

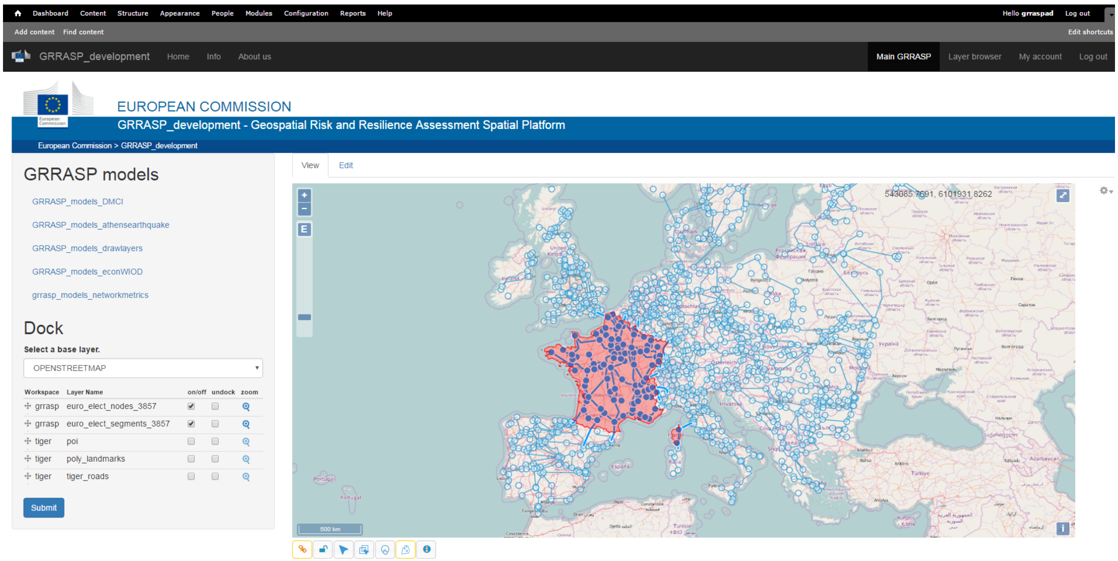

Figure 3.10: Selection by region

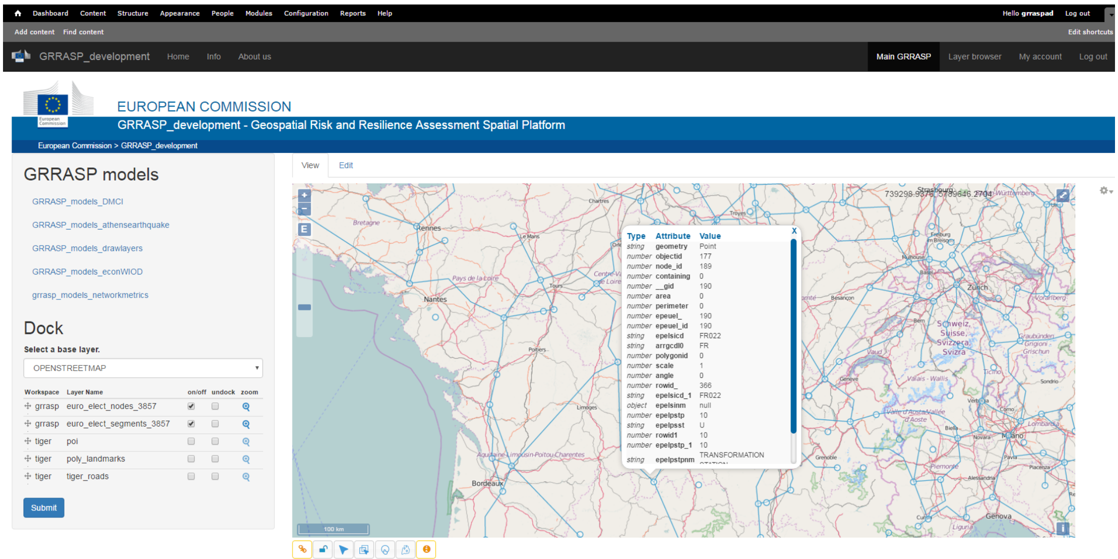

Figure 3.11: Info popup

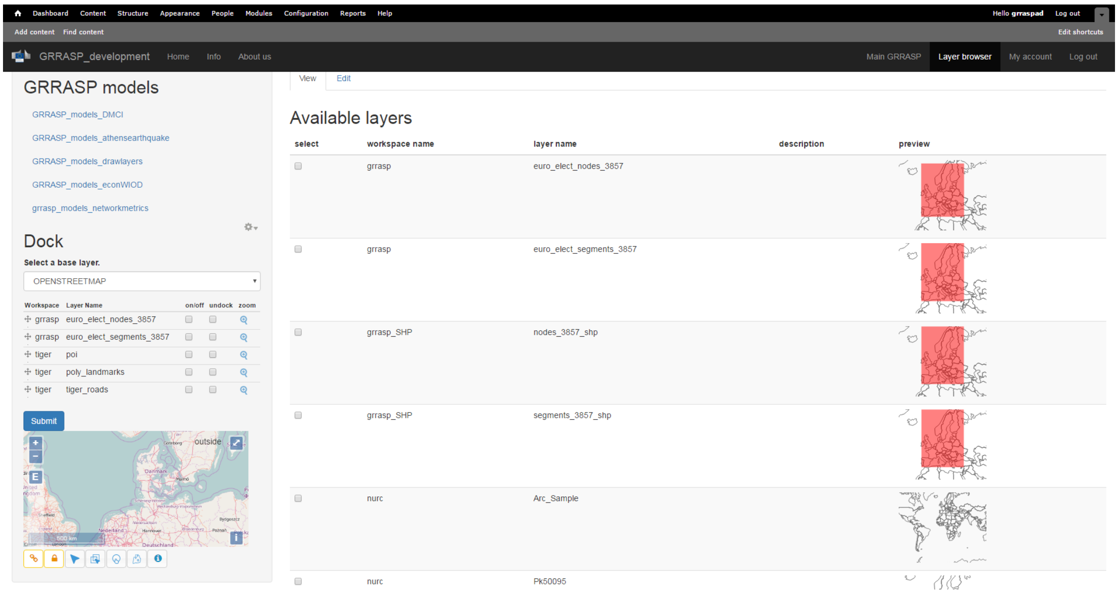

Figure 3.12: *Layer browser page*

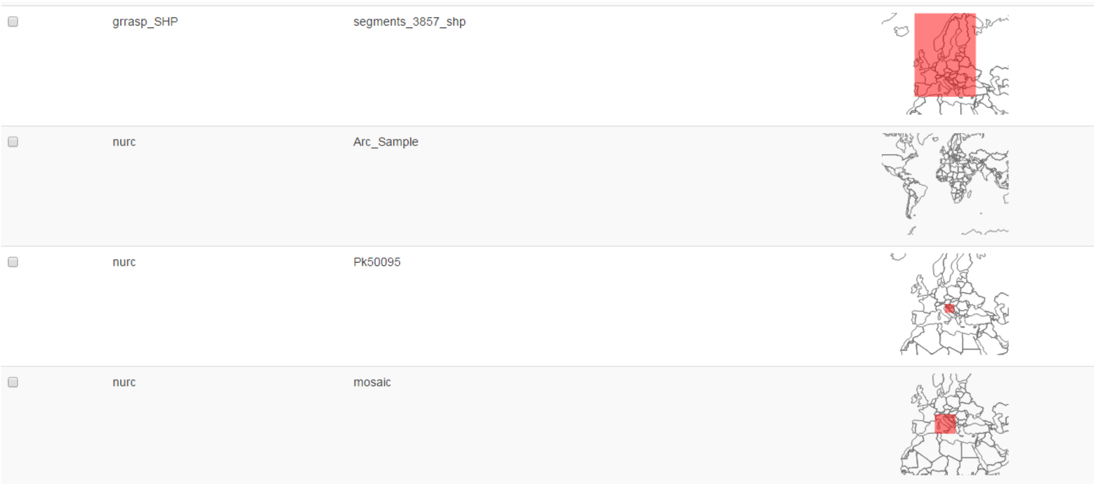

Figure 3.13: *Layer browser list with info and preview*

CHAPTER 4

Analysis Models introduced in GRRASP

This chapter describes the integration of the analysis modules developed by the JRC (or other partners) in the new architecture of GRRASP. The new architecture required substantial refactoring of the analysis modules in order to take full advantage of the new functionalities. The outcome of this process is an even more modular platform, much faster execution of analyses and more dynamic visualization of the results. In addition it will be more straightforward in the near future to interface the existing and future modules in order to exchange data in a seamless manner.

4.1 Modular structure of analysis models introduced in GRRASP

The process to introduce a new module in GRRASP is now standardised that requires a series of steps. These can be summarised as follows:

- Create a Drupal module supporting the introduction of relevant simulation parameters by the user, e.g. forms to be displayed and filled on the client-side;
- Develope and embedd the core computational software relevant to the problem in the module;
- Match the input-output requirements imposed by the architecture.

This process will be further standardised especially as far as the third point is concerned. This will enable the rapid integration of several different modules by third users. Simply the third party developers should provide the type of input that is required for their model and the type of input that it returns.

4.1.1 Creation of the supporting Drupal module

A Drupal module is a function aggregator that allows introducing new and personalized functionalities in the CMS. In Drupal 7, a basic module named *mymodule* can be created by aggregating in an homonymous folder the following three files:

- *mymodule.info*: it describes the basic information regarding the module, including dependencies on other modules;
- *mymodule.install*: it specifies the installation procedure of the module;

- *mymodule.module*: it details the actual operation of the module, e.g. the creation of blocks, the structure of a form and how the server should react when it is submitted.

Detailed information about the concept of Drupal modules and their development can be found at the project's webpages[1]. The current release of GRRASP includes some implementation instances of scientific modules and it is provided as a guideline for development.

Once a module has been created, it can be activated in Drupal through the administrator's interface or, for instance, by drush commands. In the current implementation of GRRASP, the additional/new modules are then associated to a Drupal content type and assigned a specific webpage within the architecture of the website.

4.1.2 Development and embedding of the core computational software

The CMS acts as a mediator between the user interface and the computational core of scientific module. Provided that the exchange of input-output data for the run of the models is ensured by the module described above, a number of possibilities are allowed for the development of the scientific modules.

In the provided examples, the computation resides on the server side and the computational models are provided as jar archives included in the respective modules. These have been developed starting from algorithms initially developed in Matlab and then converted to Java classes through the MATLAB Compiler SDK(TM) functionality. This allows the creation of C/C++ shared libraries, Microsoft .NET assemblies, Java classes, and Python packages starting from Matlab programs.

Once the application is converted as described above, it can deployed to the GRRASP server. Although these application are developed using a proprietary software such as Matlab, they can be shared with users without the necessity to install Matlab. This is possible thanks to the MATLAB Runtime libraries which are used for the execution of the compiled code and are available free of charge to any user and for any platform (Windows, Linux, Mac OS).

4.1.3 Input-output requirements

While flexibility in the data exchange between the computational software and the other components of the interface is allowed, we propose a semi-structured approach for the simulation output directed to the user interface. In this sense, data are organised according to the json format and we introduce an object-oriented syntax gathering the raw output data and information for the selected displaying option. This takes into account that the GRRASP user interface does not only provide map visualisation capabilities, but also complementary options (such as graphing through the d3.js library instruments).

This structured choice allows the introduction in GRRASP of new data visualisation methods and their matching with the potential requirements of scientific modules.

4.2 Case studies of models introduced in GRRASP

In this section we describe the implementation in GRRASP of two scientific modules, related to the calculation of network metrics and to the analysis of economic impact of critical infrastructure disruption.

[1] https://www.drupal.org/

4.2.1 Network analysis

An important element of any analysis related to critical infrastructures is the topological analysis of networks. Topological analysis of networks aims to evaluate metrics that are directly related to their structural characteristics. There are numerous types of metrics, e.g. clustering coefficient (many different types of clustering exist), critical paths, betweenness, connectedness, etc. In addition to these well known and established metrics we have also developed additional ones namely, criticality and vulnerability. Criticality simply identifies the downstream nodes of a network that may be impacted if a node is disrupted. On the other hand, with node vulnerability we define the upstream nodes in a network that if disrupted may have an impact on a node of interest.

A local clustering and global clustering coefficients have been implemented in GRRASP. In addition to classical algorithms from the literature, additional ones can be introduced in GRRASP. It is a matter of writing and debugging the correct module and compile it to a standalone executable that can be invoked by GRRASP. It is thus an expandable module that can accommodate more metrics is order to serve future computational needs.

In GRRASP it is possible to do this analysis selecting part of a network using the tools mentioned in previous chapters. Figure 4.1 reports an example of such kind of network analysis output.

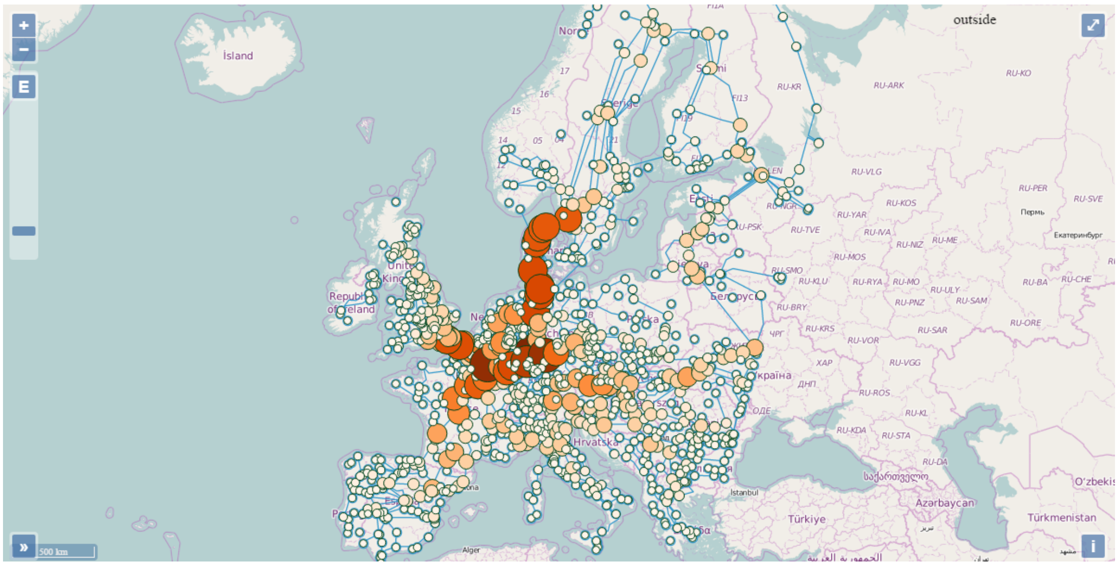

Figure 4.1: *Output of metrics model example (centrality)*

4.2.2 Analysis of economic impact of critical infrastructure disruption

This model is in fact the incorporation of CINOPSYS into GRRASP. We will not go into the details of this since it is documented in previous reports. The main motivation for incorporating CINOPSYS in GRRASP is to provide the possibility in the near future to link disruption of critical infrastructures with the associated economic impact. Currently this is done through expert opinion, in other words the expert provides information on the duration of the disruption of sectors of critical infrastructures. Further to this the analysis currently takes place only at state level, but we envisage the application of this into a regional level (NUTS 2 regions). The algorithm for the regionalisation of the Input/Output tables is already developed and it will be soon introduced in GRRASP. In order to obtain this objective, the geospatial aspect of a CI disruption is pertinent. As a consequence linking CINOPSYS with the GIS capabilities of GRRASP allows to obtain this objective.

Currently the user may select to launch the economic impact model by using the appropriate button in the toolbar. Once this is done, the user may select one of the European countries for performing the analysis. The user then needs to provide the necessary information for the sector/sectors that are disrupted. Actually the user needs to provide the initial inoperability for each sector, the duration of the inoperability before recovery starts, the duration of the recovery and whether the sector may have inventories that allow to mitigate the initial inoperability. Once the necessary data are inserted, the analysis is launched and the user obtains the output of the analysis. The model provides a complete inoperability graph for each sector, as well as the economic impact for each sector and the aggregated impact for all sectors.

Subsequently, we perform a simulation for the specified scenario. It is important to mention that this analysis takes place in the server and the results can be downloaded locally or visualised directly using the D3.js interface in GRRASP, see Figure 4.2.

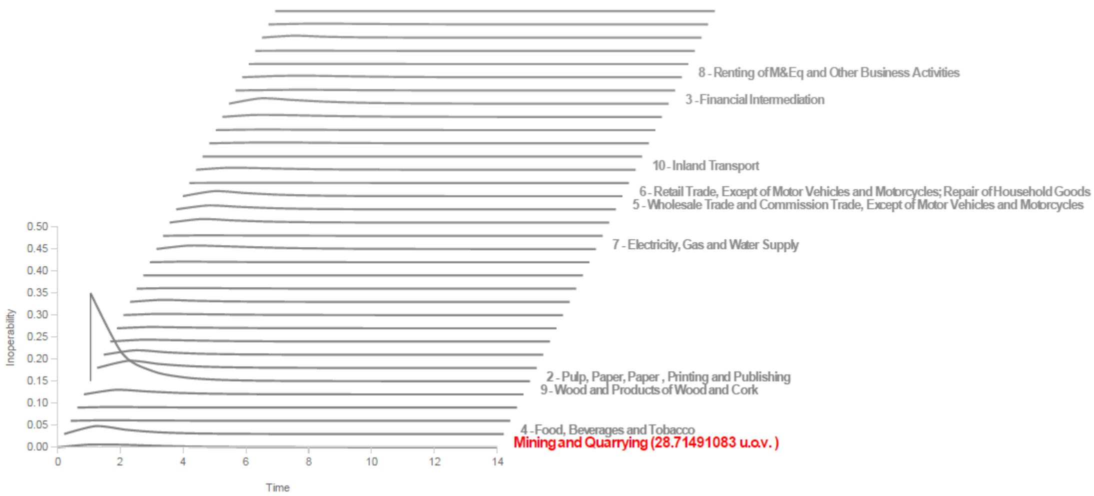

Figure 4.2: *Output of CINOPSYS model example*

4.2.3 Drawing features module

This module allows for the creation of all geometries features on the map and for setting the relative properties. All features will be saved as a GeoJson string in the database and can be provided as a layer in the layer toolbar.

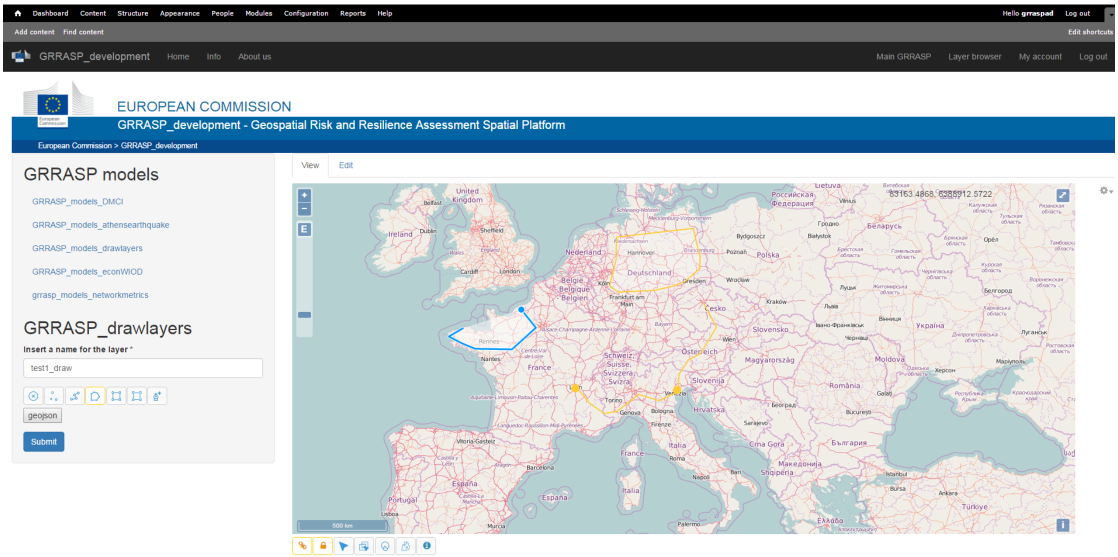

Figure 4.3: Draw main page

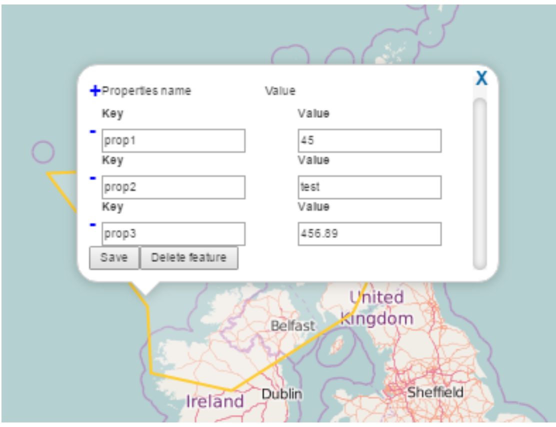

Figure 4.4: Insert properties popup

The drawing toolbar provides the activation and deactivation of the following functionalities:

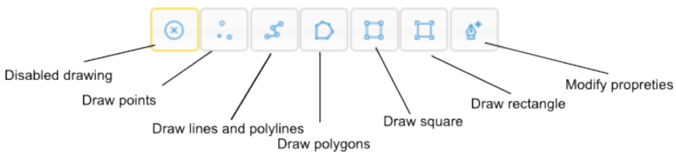

Figure 4.5: Draw toolbar

- Draw points
- Draw line or polyline
- Draw polygons
- Draw squares
- Draw rectangles
- Modify parameters

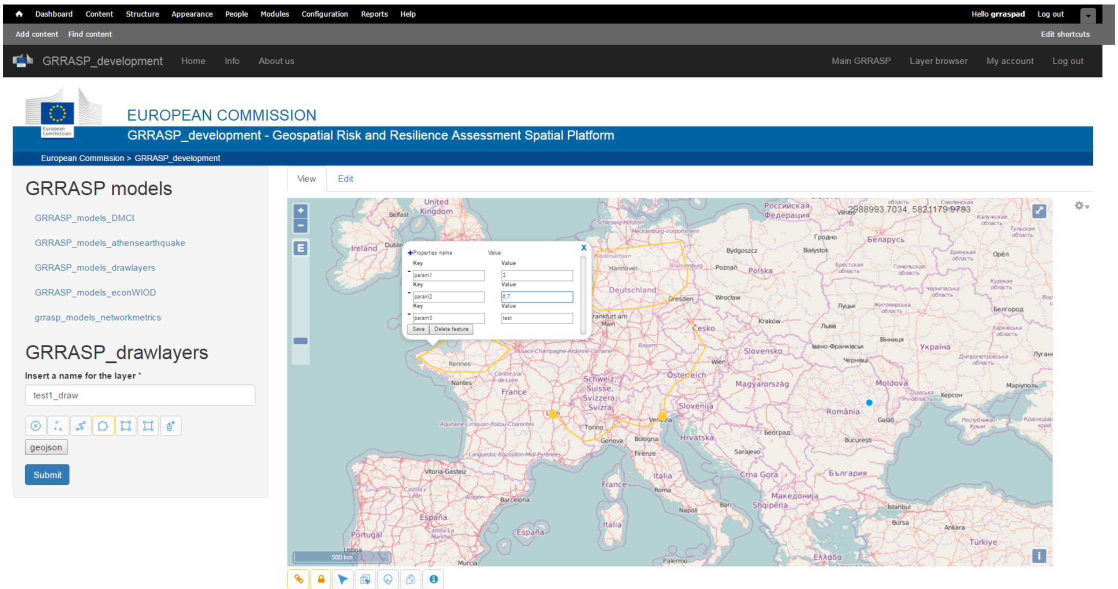

Figure 4.6: *Modify parameters*

CHAPTER 5

Concluding remarks

GRRASP can be considered as a kind of GIS operating system and the scientific modules as apps that can be installed in this environment. It combines the power of GIS systems with mathematical models in order to provide a complete analysis environment with strong visualisation and simulation focuses. The GIS layer is implemented for data entry (where applicable) and for data/analysis results visualisation as well as for taking advantage of the large amount of available libraries for performing analyses on geospatial data. In order to expand GRRASP's capabilities, the computational engine is based on Matlab developed modules that have been compiled and can be used in stand-alone mode using the Matlab Runtime Compiler (available for download free of charge). This approach facilitates the interoperability between mathematical models and web based technologies (Apache, Tomcat, etc.). In addition, GRRASP is based on a modular open architecture in order to render the system expandable and scalable to cope with future technology developments (e.g. cloud services). A server-client architecture is implemented in order to facilitate collaboration among users on common projects.

As already mentioned, GRRASP is developed having in mind the need for a collaborative environment, however, data security is a prerequisite. The architecture implemented in GRRASP strongly considers this element. In addition to that, GRRASP allows (for certain modules) uploading proprietary data, invoking the necessary module, visualising the results and then cancelling all uploaded data. This is an additional level of data security that has been implemented in order to cope with the requirements of the CIP analysis community.

In the current and perspective development of scientific modules, GRRASP follows a tiered approach (see Figure 5.1) that facilitates the engagement of actors from various fields and with different expertise.

Tier 1 (sectoral analysis). This tier constitutes the basis of most simulation software for critical infrastructure analysis and obviously there is a reason for this. Research institutes and scientists are often specialised in a particular domain and for this reason there is the tendency to develop detailed engineering models. Typically, such approaches require a high amount of specialised data. On the other hand, these models can provide very detailed descriptions of critical infrastructures and exhibit limited uncertainty, while they often require considerable development time. Further, typically they can only be used by experts in the respective field and the developers have certainly the primary ownership due to the inherent complexity of such systems. In principle the maturity in this area is high and the vast majority of actors in the field are focused on this particular Tier. In this Tier one may find models that are applicable at all levels (local, regional, national, international), however, their complexity and difficulty rather increases

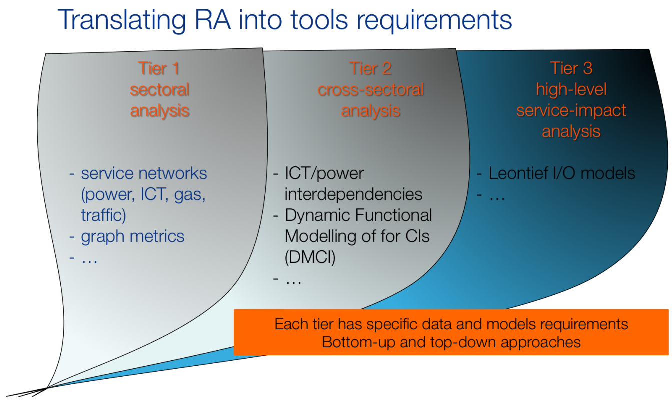

Figure 5.1: *Tiered approach*

as we scale-up towards national/international level. An example of a model in GRRASP belonging to this tier is the Geomagnetically Induced Current module that evaluates the development of geomagnetically induced currents on power grids due to the variation of Earth's magnetic field that follows severe space weather events. Another example is the one of structural analysis of networks.

Tier 2 (cross-sectoral analysis). By definition, Tier 2 includes models that require more knowledge on the interactions between sectors and less specific knowledge on the particular dynamics of a sector. Piecing together models belonging to the first tier while addressing different sectors might lead one to think to obtain an analysis of interdependent systems however, this is not the case. Although this may seem reasonable as a claim, in reality it is strenuous due to the tremendous complexity that this approach would generate and also imply a request for a huge amount of data. So it is necessary to adopt a different approach that focuses on higher-level variables such as demand and delivery of services and in that way interdependent infrastructures can be modeled with less data and also reduced complexity. Here we have much fewer models, although their complexity can be even lower with respect to Tier 1 models. It is important to mention here that Tier 2 models are applicable at all levels but certainly their real strength is shown when it comes to regional and national level. At an international level it is very important to represent large parts of infrastructures with a limited amount of information otherwise there is the risk to go towards first tier models. Tier 2 modules are related to the assessment of interdependencies between sectors of critical infrastructures. Interdependencies can be classified as functional, logical, cyber and geographical and certainly a robust interdependencies analysis module should be able to take into account all these types of interdependencies. In order to address this issue we have jointly developed with Polytechnic School of Milan an interdependencies analysis module, the DMCI (Dynamic Functional Modelling of vulnerability and interoperability of CIs)1 that takes into account the above mentioned types of interdependencies while its modularity enables the end user to define nodes of critical infrastructures on a map and establish cross-sectoral interdependencies among these assets. Among other advantages, this type of tool enables the collaboration of multiple actors in the field thus it facilitates a bottom up approach towards improving the understanding of interdependencies among sectors. Relevant application examples include the impact assessment of power grid disruptions on telecommunications or the effects of a disruption in the rail transports on the road transport network due to the transfer of service demand by the end users.

Tier 3 (high-level service impact analysis). This tier focuses on the assessment of high level impact at regional, national and international level taking input from the modules of Tier 1 and Tier 2, where relevant. In this framework we can collocate the economic impact module that has been introduced in GRRASP and is based on an inoperability Input/Output model3. This module includes enhanced features in order to describe the dynamics of the recovery process, while taking into account the existence of inventory within certain economic sectors. However, more modules are needed that can address important issues such as regionalisation of the effects of critical events. Although some of these issues can be addressed, at a first stage, with a Tier 1 module, in that case the output would not be as accurate since high order effects (interdependencies) could be omitted. GRRASP's open architecture allows third party users to enrich the modules portfolio to complement existing capabilities of GRRASP across tiers. Currently the integration of the various modules belonging to different tiers is under development. This will lead to a seamless risk and resilience assessment framework, starting from the assessment of threats at sectoral level leading to estimate interdependencies between sectors and finally reaching the assessment of the total economic impact. The inclusion of further types of impact analysis at Tier 3 is also under development. In addition to these functionalities, we have equipped GRRASP with the capability to fetch data from remote servers and use them for visualisation purposes or for initiating a Risk/Resilience analysis. This functionality enables GRRASP users to set up dynamic and interactive processes for information exchange and sharing of risk maps as well as other geospatial data. Currently such services are deployed only in a few cases.

GRRASP will be further developed through a series of projects that are ongoing or under preparation. Future plans include the development of a standardised protocol for the exchange of data among models. This is the cornerstone for building an end-to-end analysis framework for critical infrastructures.

An additional element to be further developed is the scenario builder. Currently the end user has to use each of the GRRASP modules and features independently. In the future it is expected to have a scenario builder in which the end user will define the scenario to be analysed. The type of models and data to be implemented should be part of the expert knowledge of the system. This would enable an even larger number of end users to make use of GRRASP.

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